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Navigating the Future: Using Artificial Intelligence to Improve Ports in the Blue Economy in Nigeria

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ABSTRACT: The use of artificial intelligence (AI) is quickly changing how ports as well as the blue economy operate by providing creative answers to difficult problems. This study examines how crucial AI is to improving the operation of ports and, consequently, to furthering the sustainability and effectiveness of the blue economy in Nigeria. We examine the use of adductive & inductive deduction throughout this setting, demonstrating how different models of understanding support effective processes of decision-making inside ports. An essential tool for the analysis and improvement of complex port operations involves solution set computing. Researchers also look at other logic-based artificial intelligence (AI) systems to show how flexible and adaptable they are in solving all the different issues the marine industry faces. This study launches a thorough investigation of the crucial part AI performs in the operation of ports, especially within the framework of the global blue economy. We explore the complex methods through which AI, which includes numerous reasoning perspectives including logic-based structures, supports smart decision-making procedures throughout ports. We also look at the manner in which answer response development makes it easier to understand and optimize complicated port processes.

KEYWORDS: Artificial Intelligence, Blue Economy, Agent-Based, Logic, Ports

1. INTRODUCTION

The blue economy in Nigeria, includes all commercial ventures involving aquatic environments & waterways, is a crucial pillar of global trade and ecology. Because due to the blue economy's enormous capacity to support a secure food supply, job opportunities, energy from renewable sources, & conservation of ecosystems, its importance is growing as the country's population rises (Elisha, 2019).

The use of artificially intelligent systems (AI) in this setting develops as a disruptive force, giving imaginative approaches for maximizing the complex and varied activities throughout ports. Ports are the backbone of the Nigerian blue economy because they are important land-to-water crossing points that make it easier to move commodities, individuals, & supplies.

The use of AI technology within such marine centers has the potential to boost their financial performance globally while increasing operational effectiveness and lowering the ecological footprint (Munim et al, 2020). The main goals of this article are divided into two categories. First, we want to give a thorough review of how AI is being used particularly in the Nigerian blue economy, including an emphasis on port operations in particular. Secondly, we want to provide insight on the complexity of logic-based artificial intelligence (AI) systems along with how adaptable they are to the various problems the maritime sector experiences in Nigeria

2. BACKGROUND AND RELATED WORKS

In examining background and related works, it becomes important to take two things into consideration: existing challenges in ports in the Nigerian blue economy, and a review of the Artificial Intelligence applications in port management in the blue economy in Nigeria. The existing challenges of the blue economy, is an important part of today's worldwide marketplace, is faced with numerous difficulties. These difficulties are closely related to port operations because ports are important entry points for maritime operations, especially in Nigeria. Among the principal difficulties are:

Major ports are running close to or at ability, which causes congestion and interruptions, and higher operating expenses. The increasing need for transport services makes the situation worse, especially for Nigeria that has experienced bad road networks (Jacob and Umoh,

2022). With problems including water as well as air emissions, ecosystem damage, and pollutants from transport boats, ports leave a huge ecological legacy. Sustainable development is a critical issue (Aijaz, U. and Butt, 2023).

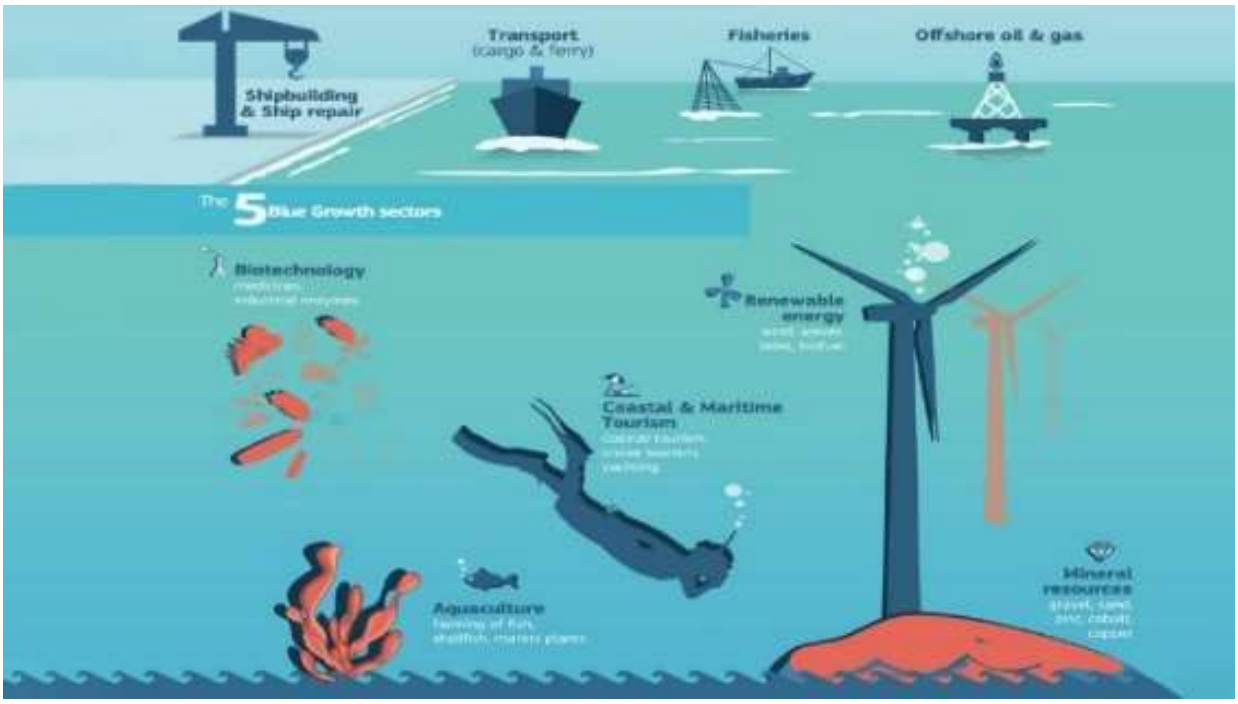

Figure 2.1: Why Blue Economy Is So Important, Source: EIR (2024)

In consideration of the AI application in port management in the blue economy of Nigeria, an increasing body of research has been published recently on the use of artificial intelligence (AI) within the management of ports & the blue economy specifically in Nigeria. The possibility of AI to handle the issues mentioned above has been acknowledged by both academics and practitioners. The advantages of solutions based on artificial intelligence are as follows:

Predictive data analysis powered by AI & continuous surveillance increase efficiency in operations by decreasing traffic & better allocating resources. By offering knowledge regarding decreasing emissions, garbage elimination, including environment maintenance, AI helps to build eco-friendly methods (Amuthakkannan et al, 2023) Utilizing sophisticated monitoring, identification of anomalies, including vulnerability testing; systems powered by AI improve protection.

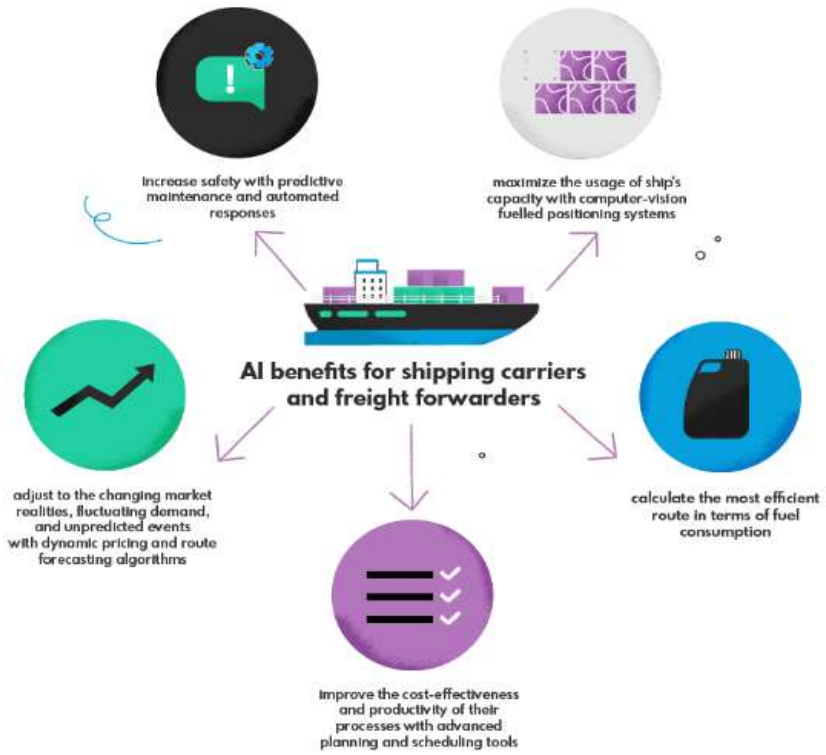

Figure 2.2.1: AI benefits for shipping carriers, logistics providers, and freight forwarders (Source: https://nexocode.com/)

Algorithms that are driven by AI help to optimize regular consumption, organizing, and distribution of resources. Artificial intelligence (AI) models make it easier to detect and handle risks by anticipating and addressing interruptions in supply chains around the world. Technologies like self-driving boats, intelligent logistics, and eco-friendly transportation techniques are supported by AI (Lambert et al, 2019)

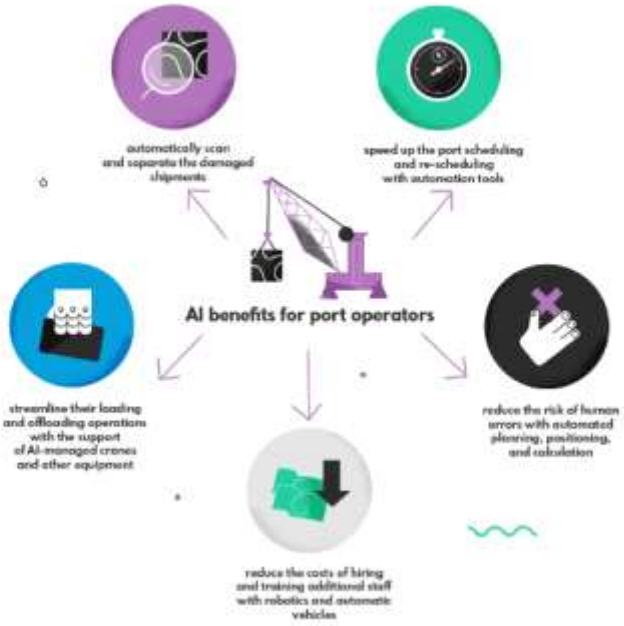

Figure 2.2.2: AI benefits for port operators (Source: https://nexocode.com/)

2.1 Logic Based AI System for Ports

2.1.1 Principles of Abductive and Inductive Reasoning

The technique of deducing the explanation that is most probable for a group of experiences or pieces of data is known as adductive logic. Adductive reasoning is frequently used at ports to identify and foresee future problems like equipment breakdowns or problems with scheduling (Attri, 2020). It enables proactive solutions to problems throughout the port's operations by enabling artificial intelligence (AI) systems to come up with defensible decisions according to the information at their disposal.

Making generalizations trends and patterns through particular data is the goal of inductive logic. In ports, previous information on vessel congestion, container quantities, including atmospheric conditions are able to be analyzed using inductive analysis. AI systems are able to predict outcomes and offer suggestions for improving port scheduling, distributing resources, and repair programs by spotting repeated trends (Okoli, 2023).

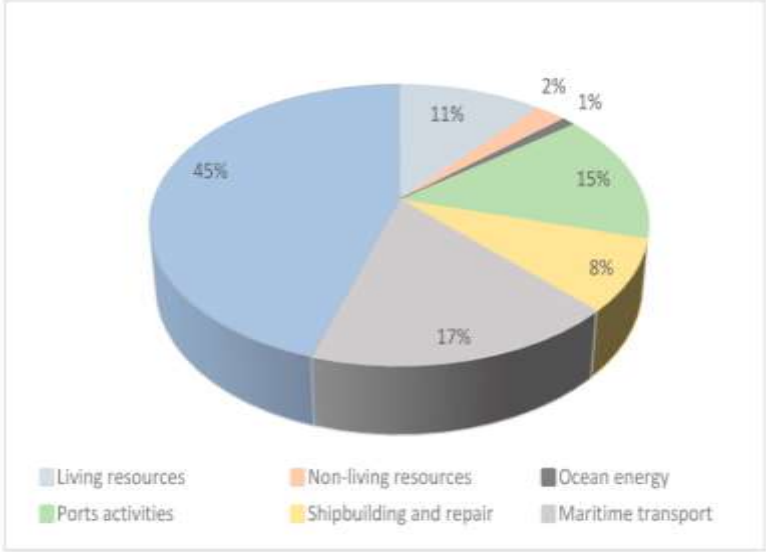

Figure 3.1. Value added at factor cost (% of total value added of the blue economy, 2019)
(Source: Eurostat, authors' calculations.)

2.1.2 Answer Set Programming (ASP) in Modelling Complex Port Operations

Answer Set Programming (ASP), which offers an explicit yet expressive programming style for analyzing difficult issues with decision-making, is crucial for describing and enhancing the intricate & dynamic activities underlying ports. When it comes to ship organizing, handling cargo, & allocation of resources, ASP may be utilized to describe a variety of restrictions, dependency issues, and goals (Bond, 2019). For port-related tasks, ASP solutions can effectively comb through a wide search area to find of ideal or nearly ideal solutions.

When it comes to arranging vessel departures and arrivals, assigning berths, & streamlining the process of loading and offloading of goods, this expertise is important. Ports can deal with unanticipated incidents, which include severe weather or malfunctions in equipment, despite reducing disturbances to the entire operation, because to ASP technologies' ability to respond to fluctuating situations in instantaneously (Opfer et al, 2016).

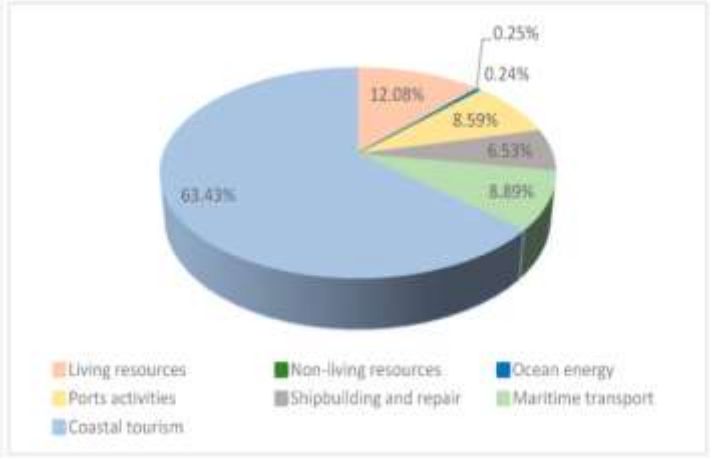

Figure 3.2. Persons employed by sector (% of total employment in the blue economy, 2019). (Source: Eurostat, authors' calculations)

2.1.3 Other Logic-Based AI Systems and Their Relevance to Improving Ports

Beyond ASP using adductive reasoning, many kinds of logic-based AI techniques improve ports: Artificial intelligence (AI) systems are able to manage & evaluate contradictory facts and personal tastes with the help of reasoning structures (Dalaklis et al, 2023). This might help in procedures for making decisions in handling ports because there are several players and considerations. Temporal restrictions & event-triggered activities are just two examples of the dynamic characteristics of port processes that can be discussed using non-classical reasoning like modality and dynamic logical reasoning (Timchenko et al, 2022).

Logic-based techniques enable a comprehensive understanding of port operations by facilitating the integration of various data sources and developing uniform information abstractions (Saidi et al, 2019). Ports represent changing places with many different parties and organizations involved. Multi-agent network logic offers a structure for simulating and improving connections among various entities, resulting in more productive and cooperative port management (Yalçın et al, 2023).

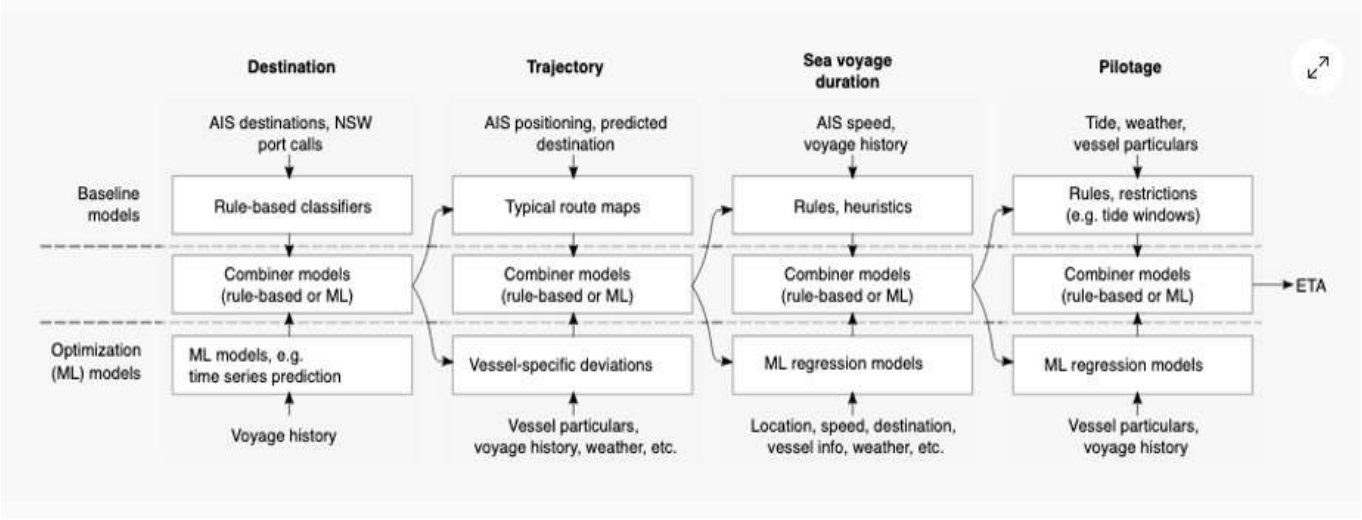

Figure 3.3: Modular Structure (Source: https://www.awake.ai/)

2.2 Application of Logic Based AI Ports

2.2.1 Current Applications

Numerous uses for artificial intelligence & logic-based technologies have been discovered at ports, changing conventional methods and increasing overall effectiveness: Vessel Transportation Management: AI-driven platforms for managing vessel traffic utilize logic-based processing to plan routes for vessels, anticipate arrivals, and reduce congestion. Such devices are also helpful when making decisions in the face of bad weather and unplanned delays (Hassan and Alam, 2019). Ports use artificial intelligence (AI)

algorithms for arranging berth distribution, taking into account variables like vessel measurement, cargo category, and the availability of resources (Kelly et al, 2021). Technologies built on logic ensure effective berth utilization and speed up processing times.

Cargo Handling: Activities involving the arranging them, launching, & offloading of containers are managed by artificial intelligence (AI) systems utilizing logic-based understanding (Kim et al, 2022). They guarantee effective cargo handling while upholding security & limited resources. Maintenance Development: Logic-based AI helps with preventative maintenance by examining equipment sensor data. It anticipates problems, plans repair efforts, and reduces unavailability (Clemente et al, 2023).

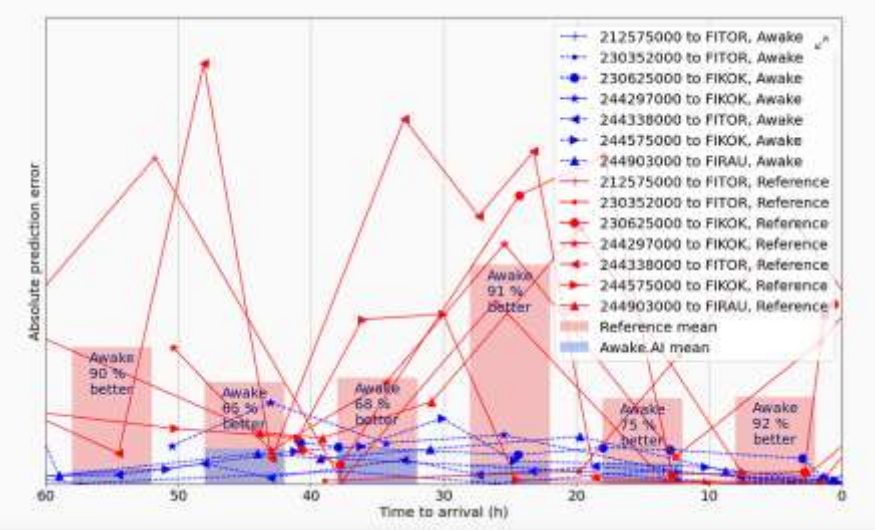

Figure 4.1.1: ML-based ETA optimization (Source: https://www.awake.ai/)

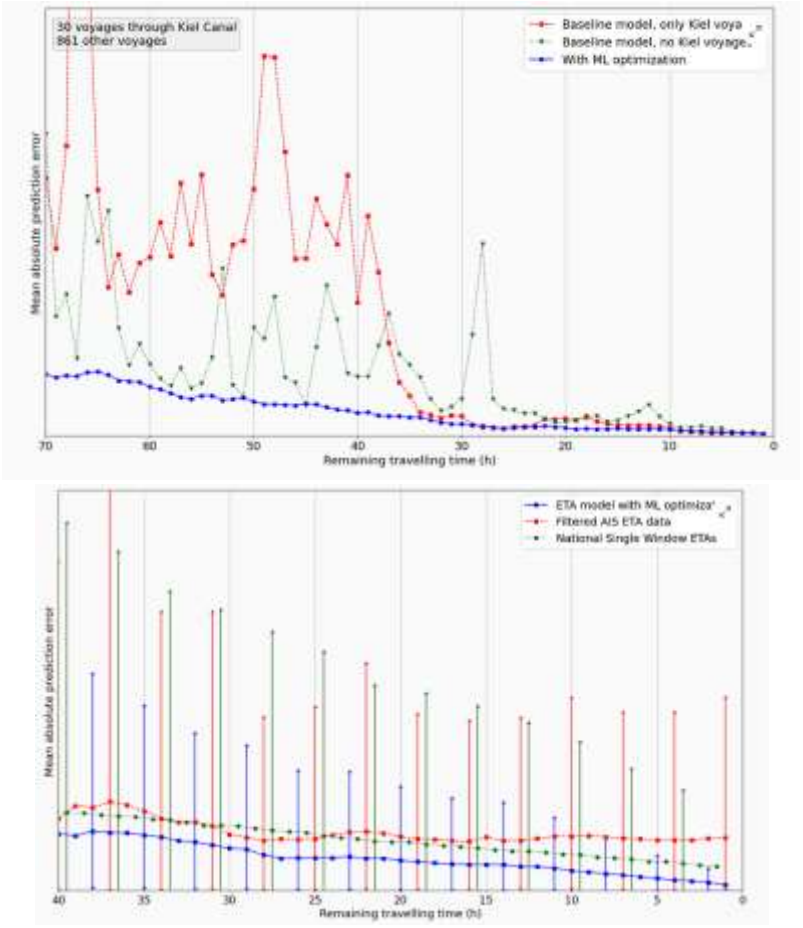

Fig 4.1.2: ML-based ETA optimization (Source: https://www.awake.ai/post/ai-for-smart-ports-port-call-prediction-part2)

2.2.2 Case Studies and Projects

The practical advantages of logic-based artificial intelligence (AI) systems through port management are illustrated by a number of important instances & initiatives, including:

The Netherlands' Port in Rotterdam uses logic- and AI-based systems for overseeing docking timetables & vessel traffic. The effort has lowered traffic, increased fuel economy, and improved the environment. The achievements of Rotterdam are an example of other significant ports throughout the world (Kopp et al, 2021). Port of Singapore as follows: The port greatly lowers downtime for equipment as well as servicing expenses by anticipating repair requirements.

Automated Container Terminals: Automatic cargo terminals, like those in the Chinese city of Qingdao & Germany's Hamburg, use AI to make decisions about managing containers in real time. The management of container actions, preservation, & retrieval in order by logic-based devices leads to a quicker turnaround & greater productivity (Lagasco et al, 2019).

Port of Long Beach, California, USA: To improve the handling of cargo, the terminal at the Port in Long Beach created AI-based operations technologies. These methods lower pollutants cut down on transportation rest periods, as well as effectively manage commodities using logic-based understanding (Lan et al, 2024).

2.3 Automating and Computational Complexity

2.3.1 Automated Reasoning Techniques in Port Optimization

In order to improve shipping processes, computerized reasoning approaches, such as compatibility testing & its expansions, are essential:

Checking for Satisfiability: To assess the viability of logical requirements & designs, port efficiency uses satisfaction verifying, an essential machine-learning approach (Leclerc and Ircha, 2023). It assists in determining if suggested planning, allocating resources, or transportation methods correspond to established limitations in this setting, thereby guaranteeing that activities go without a hitch (Feljan et al, 2017)

Modifications for Advanced Issues: Variations of satisfactory testing like mixed-integer programming (MIP) & constraint logic programming (CLP) are employed in sophisticated port improvement situations. Although CLP enables the simulation of complicated limitations, therefore being suited for the distribution of resources and time management in ports, MIP modelling enhances linear & mixed-integer issues in programming (Dinh et al, 2024).

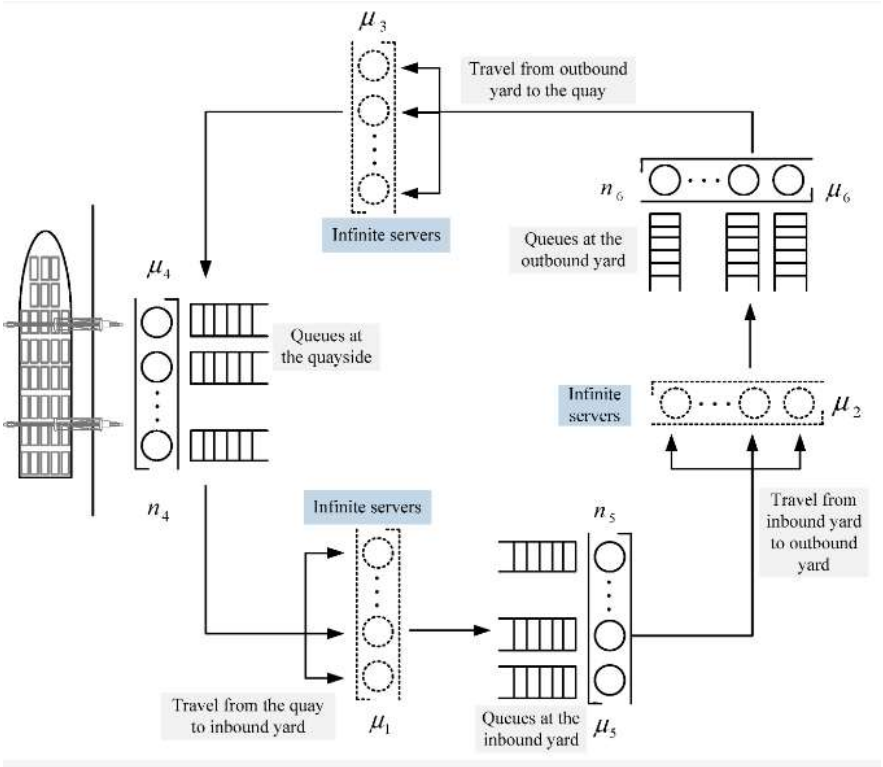

Figure 5.1: Operational network of the system. (Source: https://www.mdpi.com/2071-1050/14/24/16869)

2.3.2 Computational Complexity in Logic-Based AI Systems

Computational difficulties arise when deploying logic-based artificial intelligence (AI) systems within practical problems port circumstances. Port difficulties with optimization sometimes entail a sizable search area with many of different factors and restrictions (Mudoola, 2021). Such broad search regions can make it technologically and time-intensive to find the best solutions.

Making judgments fast is necessary since ports function in instantaneously. AI systems built on logic have to negotiate a compromise between the necessity for precise execution and the requirement for rapid reaction to changing circumstances. Ports contain a certain amount of computing resources, including memory and processing power. AI systems built around logic must function effectively within these limitations (Calegari et al, 2020).

Ports represent dynamic settings, with factors such as vessel flights, climate conditions, & accessibility to equipment continually shifting. AI systems built on logic should instantly react to such developments. Scaling Issues: It can be difficult to control the processing requirements for logic-based AI systems when ports expand in their scope and complexity. Durability is a crucial factor to take into account when implementing them (Munim et al, 2020).

Researchers and those working in the area of port maximizing efficiency are constantly creating algorithms, intuition, and methods of optimization that strike an appropriate equilibrium between the use of computing power with the standard of the solutions in order to handle these challenges of computation. In order to improve the effectiveness of logic-based artificial intelligence (AI) algorithms in port contexts, developments in distributed and parallel computer science are also being investigated. With these initiatives, it will be possible to maintain the viability and efficiency of AI-driven port efficiency despite the technological difficulties presented by actual operations at ports. (Calegari et al, 2021).

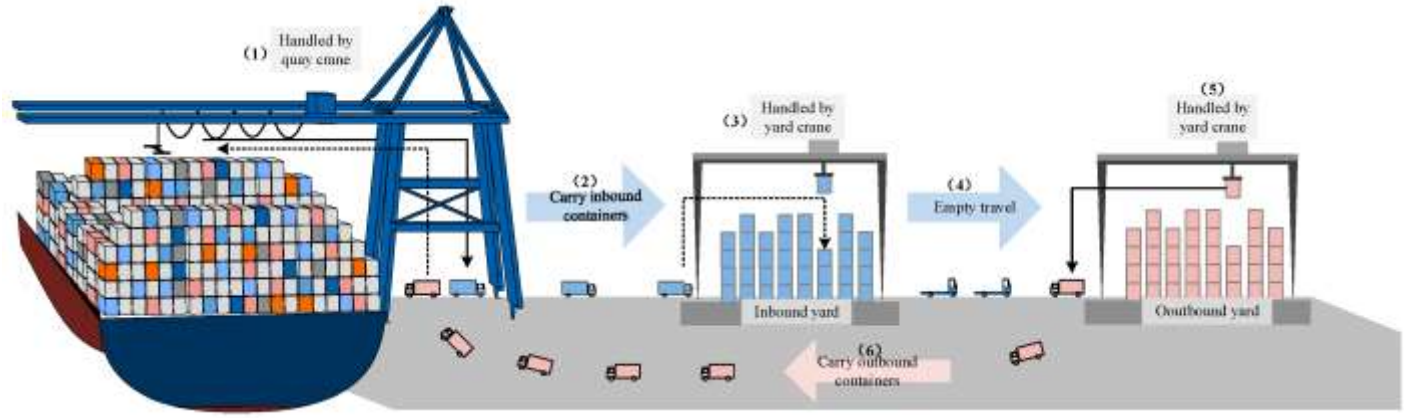

Figure 5.2: Overall container terminal operations with double cycling.
(Source: https://www.mdpi.com/2071-1050/14/24/16869)

2.4 Knowledge Representation and Integration

2.4.1 Importance of Knowledge Representation in AI-Driven Decision-Making

The foundation of AI-driven choices in ports involves the representation of knowledge, which provides an organized method to gather, arrange, and use data:

Complicated maritime operations include processing cargo, arranging vessels, doing maintenance, and other activities (Petrea et al, 2021). Modelling these complicated procedures is made possible by a model of knowledge, which offers a formal foundation for expressing domain-specific information.

Support for choices: In port administration, choices must be executed precisely and effectively. Machine learning algorithms can offer assistance with choices and suggestions for optimization because the representation of knowledge makes it easier to encode rules, restrictions, and specialist knowledge (Michael et al, 2024)

Real-time adjustment is necessary since ports work in actual time and events may shift quickly (Sepponen, 2021). By keeping and revising information concerning the condition affecting the port's operations at the moment while making choices based on the information, this knowledge representation allows AI systems to evolve.

Interaction is improved throughout port environment participants by efficient information visualization. It offers a standard terminology & structure for sharing knowledge and promoting cooperation & organization (Lee, 2024).

2.4.2 Challenges and Solutions in Logic-Based Data Access and Integration

Logic-based information access and utilization in port contexts might present significant difficulties, however, there are alternatives available:

Heterogeneous Data Sources: Sensors, such as databases, plus outside networks are only a few of the different sources from which port data is derived. Systems using logic have to manage information of a variety of types and patterns. Ontologies along with other semantic computing technologies can offer a common language and architecture for integrating data (Koka, 2022).

Data Volume: Ports produce enormous volumes of data, which presents scalability problems. Large datasets are capable of being effectively organized and processed with the use of decentralized systems & cloud-based applications (Setiyowati et al, 2022).

Instantaneous information is necessary for logic-based artificial neural networks to make decisions. Real-time information streams through devices as well as additional sources can be ingested and analysed using data processing & dependent on events systems.

Data Consistency: Reliability and assurance of quality are essential for successful decision-making. To solve this problem, the information flow can incorporate verification of data & cleaning procedures (Branting, 2017)

Safety and confidentiality: Private information is frequently present in port data. To secure information security and confidentiality, effective control over access methods and technologies for encryption remains crucial (Kharlamov et al, 2017)

Connectivity using Legacy Networks: Ports could utilize unique types of data in their current systems. The discrepancy connecting past technologies including logic-based artificial intelligence (AI) platforms is capable of being filled by bridging technologies along with information adapters (Basloom et al, 2020).

2.5 Logic Based AI for Uncertain Environment

2.5.1 Handling Uncertainty and Probabilistic Reasoning in Port Operations

The management of unpredictability and logical reasoning amid the constantly changing and unpredictable atmosphere of shipping operations is crucially aided by logic-based AI structures:

Variable Information Inputs: Ports frequently get information from a variety of different sources like atmospheric sensors & ship tracking gadgets, which could be noisy or inaccurate. Probabilistic algorithms can be used by logic-based artificial intelligence (AI) systems to take uncertainty in information into account while generating judgments according to the probabilities of various outcomes (Alyami et al, 2019).

Ports depend on forecasts for vessel arrivals, cargo volumes, and especially machinery efficiency. Probabilistic methods for predicting can be included by logic-based artificial intelligence (AI) algorithms to produce more precise and accurate probabilistic estimations, enabling improved utilization of resources and management (Thoya, 2022).

Risk assessment: Evaluation of risks in the port industry, involving security and risk assessments, is inevitably unpredictable. Probabilistic inference can be used by logic-based artificial intelligence (AI) algorithms to evaluate and reduce risks by taking into account various possible outcomes including the chances connected to each one (Nguyen et al, 2021).

Real-time mitigation: Port circumstances are subject to quick changes, making it difficult to predict what to do next. AI systems with a logic-based foundation can constantly update their comprehension & judgments according to real-time input, changing their strategies and plans as necessary (Nguyen, 2020)

2.5.2 Role of Non-Classical Logics in Addressing Uncertainty

Risk during the port's operations can be managed with the help of non-classical logical systems, which include modal in nature, short-term epistemic, changing, geographical, paraconsistent, & a combination of logics:

Modal logic may simulate different scenarios & consequences in ambiguous situations because it may represent option & inevitability. For instance, it might symbolize the potential for breakdowns of equipment & their effects (Vieira et al, 2020).

Temporal logic is the study of the sequence of events. This is capable of being applied to port operations in order to simulate the spatial characteristics of vessel timetables, schedules for repairs, as well as other immediate jobs while taking scheduling variability into account (Weir, 2024).

Epistemic Logic: Information and opinions are represented using epistemological logic. This may be employed in ports to simulate the understanding of various players, such as port administrations, shipping firms, and transportation suppliers, as well as to analyze their assumptions and limitations (Klein, 2021)

Hybrid logic incorporates elements of many non-classical logical concepts, making it possible to describe uncertainty and complicated dependencies in port procedures in a way that is both extremely adaptable and descriptive (Dean and Elliott, 2017)

Logic-based artificial intelligence systems may efficiently incorporate the ability to think about unpredictability by utilizing non-classical logical systems, giving maritime managers the skills, they need to arrive at conclusions despite the possibility of unforeseen events including changing circumstances. Such logic improves the endurance and flexibility of artificial neural networks in ambiguous port situations, resulting in greater security and better-performing blue economy activities.

2.6 Logic Based AI in Multi Agent Systems

2.6.1 Examples of Logic-Based AI in Managing Multi-Agent Systems within Ports

The complicated surroundings of the port present a considerable challenge for logic-based artificial intelligence systems when handling multi-agent networks:

Vessel Traffic Administration: In ports, there are frequently a number of different organizations that operate within the same area, such as ships, tugboats, plus captains. Communications and coordination techniques are used by logic-based artificial intelligence (AI) algorithms to control ship traffic statistics, assuring secure and effective port operations (Zhou et al, 2019).

Allocation of Resources: For shipping operations to be effectively successful, materials like scaffolding, docks, & labor must be efficiently allocated. The distribution of resources and agreements between various interested parties can be facilitated by logic-based systems with several agents, maximizing resource usage and avoiding disputes (Prokudin et al, 2018).

Transporting cargo among automobiles, vessels, and storage requires the coordination of several agencies. Artificial intelligence (AI) platforms with logic-based scheduling and tracking capabilities may plan and monitor shipment movements while taking into consideration the needs as well as tastes of various individuals (Winther and Su, 2020).

2.6.2 Applications in Game Theory and Social Choice for Port Optimization

Additionally, the theory of games & the theory of social choices have uses for logic-based artificial intelligence (AI) systems, which benefits port optimization:

Game Theory: To examine the tactical relationships between entities throughout the port environment, game-theoretic simulations are employed. As an example, game theory-based pricing systems may be utilized to efficiently distribute berths or port services. In certain game-theoretic situations, logic-based artificial intelligence (AI) systems may determine equilibrium tactics & achieve the best results (Kurt, 2018).

Theory of Social Choice: Port choices can include a number of parties with different perspectives. The concept of social choice hypothesis aids in combining these individual tastes to reach judgments as a group. Social decision theory-based polling methods & choice accumulation techniques can be implemented by logic-based artificial intelligence (AI) machines to find the best port rules, tariffs, or distributions of resources that balance the needs of different stakeholders (Sen, 2020).

Cooperation, integration, and dispute resolution amongst various entities are facilitated by the integration of logic-based Intelligence into systems with multiple agents across ports. It makes it possible to allocate resources more effectively, handle traffic with less difficulty, and make better decisions. Furthermore, the use of the theory of games & the theory of social choice in port management improves equality as well as openness in making decisions, which helps the maritime economy function better altogether (Dimitriou, 2021)

2.7 Planning Diagnosis and Causality in Port Management

2.7.1 Logic-Based AI Systems for Planning and Diagnosing Issues in Ports

AI systems built on logic are essential for organizing and recognizing problems in port administration: Planning: Using clever organizing, logic-based artificial intelligence (AI) platforms help to optimize the operation of ports. To create ideal or almost ideal timetables for ship departures and arrivals, distribution of resources, and cargo management, they make use of formal structures using logic. In order to guarantee effectiveness and efficiency in shipping operations, such structures take an assortment of restrictions, choices, & goals into consideration (Yalçın et al, 2023).

Diagnosis: Logic-based artificial intelligence (AI) tools are used to identify the underlying causes of problems or disturbances in ports. The aforementioned systems examine the information provided & deduce some of the significant causes of the issue using causal frameworks along with information encoding. The AI system, for instance, may determine whether or not an interruption in cargo offloading is a consequence of equipment malfunction, or a lack of workers, among other circumstances (Gorgulu and Akilli, 2016)

2.7.2 Importance of Reasoning about Actions and Causality in Port Management

In port supervisors, causal analysis is essential for a number of purposes. Problem-solving: Ports contain constantly changing environments with a variety of related procedures. Port managers can recognize problems and take appropriate action by knowing the causes of occurrences and actions (Zhang et al, 2021). By identifying the root causes of issues, immediate remedial measures can be performed to reduce interruptions.

Efficient Planning: Effective planning requires careful consideration of potential outcomes. Port managers must foresee how scheduling choices, allocation of resources, along with upkeep tasks will affect the efficiency of the terminal as a whole. Causal inference makes sure that strategies are well-informed and efficient (Ghafarzadeh et al, 2021)

Allocation of Resources: Logic-based artificial intelligence (AI) systems make effective resource allocations by using causal inference. Ports may maximize the utilization of resources and reduce disputes by analyzing the underlying consequences of decisions regarding resource allocation, including assigning certain berths or facilities to boats (AKL, 2022)

Causality is crucial to the protection & risk administration process in ports. Ports need to identify the root causes of safety problems and put preventative measures in place. Furthermore, by comprehending the root reasons behind dangers, ports can create efficient mitigation techniques (Sakita et al, 2024).

Decision-making, resolving issues and capacity for planning within the management of ports are improved by integrating logic regarding activities and consequences through logic-based artificial intelligence (AI) machines. In order to manage ports more successfully, effectively, as well as effectively under the framework of the blue economy, such instruments give port managers invaluable insights into the connections among activities & their results.

2.8 Future Direction and Challenges in Logic Based AI for Ports

2.8.1 Emerging Trends and Potential Advancements

The sophistication of AI-driven analytics for prediction will rise, allowing for more precise prediction of ship arrivals, and cargo papers, including the efficiency of equipment. This will improve resource allocation, lessen traffic, and increase the effectiveness of the port's activities.

Smart ports will be possible because to the fusion of autonomous technologies and logic-based AI systems. Intelligent coordination of autonomous ships, cranes, and logistical activities will create port environments that are safer, more effective, and environmentally benign (Sadiq et al, 2021).

Real-time decision assistance will be provided by logic-based AI systems, allowing port managers to react quickly to changing circumstances and unforeseen disturbances. This will reduce downtime, increase security, and maximize resource use (Filom et al, 2022)

Ports will use IoT sensors and gadgets more frequently to gather real-time data on machinery, cargo, including the surrounding environment. Analyzing and interpreting this information will be a key part of how logic-based AI systems improve shipping operations as well as environmental initiatives (Xiao et al, 2024). Through sophisticated monitoring, detection of anomalies, & threat evaluation, logic-based artificial intelligence (AI) platforms will improve the safety of ports. The key port systems will be protected from online threats by combining elements of logic-based AI and cybersecurity mechanisms.

2.8.2 Challenges and Limitations

Integrating and verifying the accuracy of different sources of information continues to be difficult. To fully utilize the capabilities of logic-based AI systems, ports have to make investments in organizing information along with integration technologies. Concerns about confidentiality and safety are raised by the gathering and evaluation of private port information. These issues will be addressed, and following data privacy laws will be a top focus (Wang et al, 2021).

Resources such as computational capacity and qualified employees may be limited for ports. Implementing and maintaining logic-based AI systems involves careful design and financial investment. It might be challenging to integrate logic-based artificial intelligence (AI) systems with previous technologies and current maritime infrastructure. It will be crucial to guarantee compatibility and seamless transitions (Filom et al, 2022).

In order to promote secure and accountable AI use as it becomes more autonomous, legal frameworks and ethical standards for maritime operations are going to change. For ports to effectively utilize the endless possibilities of logically driven AI systems in their search of environmentally friendly, effective, and lucrative blue economies, it will be essential to navigate these difficulties and constraints while making the most of new trends and developments (Clemente et al, 2023).

3. METHODOLOGY

The research methodology adopted for this study is qualitative in nature, implemented through a systematic literature review approach. This methodology involved collecting and analyzing data from previous studies conducted by other researchers in the field. The systematic literature review process was executed using Google Scholar, a comprehensive digital platform that provides access to a wide range of academic resources. These resources include e-books, conference proceedings, academic papers, and articles, all relevant to the research domain. A rigorous selection process was employed to ensure the relevance and quality of the data. Ultimately, a total of 21 scholarly articles were selected and analyzed, forming a robust foundation for addressing the research questions and advancing understanding in the subject area.

4. FINDING AND RESULTS

The study revealed that Nigerian ports face significant challenges, including congestion, high operational costs, poor infrastructure, and environmental degradation. These issues hinder efficiency and sustainability in the blue economy. However, the application of Artificial Intelligence (AI) shows promise in mitigating these challenges. AI enhances operational efficiency through predictive analytics, resource optimization, and eco-friendly practices while improving security via anomaly detection and risk management systems.

Logic-based AI systems, including abductive and inductive reasoning, enhance port operations by enabling predictive maintenance, resource allocation, and scheduling optimization. Answer Set Programming (ASP) effectively models complex port activities, improving vessel scheduling and cargo handling. Additionally, dynamic and multi-agent logic frameworks address decision-making challenges in ports, fostering collaboration, adaptability, and resilience to disruptions, thereby optimizing overall operational efficiency and sustainability.

Logic-based AI systems significantly enhance port operations by optimizing vessel traffic, berth allocation, and cargo handling. These systems also support predictive maintenance, reducing downtime and costs. Case studies, such as Rotterdam, Singapore, Qingdao, and Long Beach, demonstrate the effectiveness of AI in improving efficiency, reducing congestion, lowering emissions, and enabling real-time decision-making for sustainable port management.

Automated reasoning techniques, including satisfiability checks and advanced methods like mixed-integer programming (MIP) and constraint logic programming (CLP), optimize port operations by addressing resource allocation and scheduling challenges. However, computational complexity poses challenges, such as handling vast search spaces, dynamic conditions, and scalability. Innovations in distributed computing and optimization algorithms are essential for enhancing the efficiency and sustainability of AI-driven port systems.

Knowledge representation enables AI-driven decision-making in ports by organizing complex maritime data, supporting optimization, and adapting to real-time changes. Challenges like heterogeneous data sources, scalability, and data consistency require solutions such as semantic technologies, cloud computing, and data validation. Effective integration enhances collaboration, ensures security, and bridges gaps between legacy systems and modern AI platforms for efficient port operations.

Logic-based AI effectively manages uncertainty in port operations using probabilistic reasoning to handle noisy data, improve predictions, and assess risks. Non-classical logics, including modal, temporal, and epistemic logic, enhance decision-making under uncertainty by modeling complex dependencies and dynamic scenarios. These approaches improve real-time adaptability, resilience, and efficiency, supporting secure and optimized maritime operations in unpredictable environments

Logic-based AI enhances multi-agent systems in ports by optimizing vessel traffic, resource allocation, and cargo coordination. Game theory and social choice applications improve strategic decision-making, ensuring fairness and efficiency. These systems foster collaboration, resolve disputes, and streamline operations, enabling secure and equitable port management. The integration of such approaches significantly improves the maritime economy's overall performance and transparency.

Logic-based AI systems enhance port management by optimizing planning and diagnosing issues through causal analysis. They create efficient schedules, identify root causes of disruptions, and enable effective resource allocation. By reasoning about actions and consequences, these systems improve decision-making, risk management, and operational efficiency, ensuring smoother port operations and fostering sustainability in the blue economy.

Emerging trends in logic-based AI for ports include enhanced predictive analytics, smart port technologies, and real-time decision support, improving resource allocation, safety, and operational efficiency. However, challenges such as data integration, cybersecurity, resource limitations, and compatibility with legacy systems remain. Addressing these issues while adhering to privacy laws and ethical standards will be crucial for future advancements in port management.

5. DISCUSSION

The study identifies key challenges facing Nigerian ports, such as congestion, high operational costs, inadequate infrastructure, and environmental degradation, which hinder operational efficiency and sustainability. However, the integration of Artificial Intelligence (AI) presents significant potential to address these issues by enhancing efficiency and promoting sustainability (Mudoola, 2021). AI, particularly logic-based systems, plays a crucial role in optimizing resource allocation, vessel scheduling, and cargo handling. AI-powered predictive maintenance can anticipate equipment failures, reducing downtime and preventing disruptions. Additionally, AI addresses port congestion and improves environmental sustainability by fostering eco-friendly practices and reducing emissions (Hassan and Alam, 2019).

Dynamic and multi-agent logic frameworks, like Answer Set Programming (ASP), support decision-making by enhancing adaptability and collaboration among port stakeholders, increasing resilience to disruptions. Case studies from major ports such as Rotterdam, Singapore, Qingdao, and Long Beach demonstrate the benefits of AI, including reduced congestion, improved real-time decision-making, and enhanced sustainability (Michael et al, 2024)

Despite these advancements, challenges persist, particularly computational complexity. Handling large datasets, dynamic conditions, and scalability issues requires advanced optimization techniques. Innovations in distributed computing and algorithms are essential to overcome these barriers (Alyami et al, 2019).. Effective knowledge representation is also vital for AI implementation. By organizing complex maritime data, AI facilitates better decision-making and smoother port operations, but challenges like data consistency and scalability must be addressed using semantic technologies, cloud computing, and data validation (Nguyen, 2020).

AI also manages uncertainty in port operations using probabilistic reasoning to handle noisy data, improve predictions, and assess risks. Non-classical logics such as modal and temporal logics enhance decision-making under uncertain conditions, ensuring resilient operations. AI's role in multi-agent systems further optimizes vessel traffic, resource allocation, and cargo coordination, promoting cooperation and fairness, which is essential for efficient port management (Vieira et al, 2020).

Looking ahead, emerging trends such as smart port technologies and real-time decision-making will improve operational efficiency and sustainability. However, challenges related to data integration, cybersecurity, and resource limitations remain. Addressing these issues will be critical to advancing AI-driven port management and fostering sustainable growth in the maritime sector (Filom et al, 2022).

6. CONCLUSION

The key role that reasoning-based systems powered by AI have in revolutionizing port management and fostering the blue economy has been examined in this study. Important conclusions from our debate include: Intelligent answers to the complexity, unpredictability, and changeable characteristics associated with shipping operations are provided by AI-driven systems built on logic-based reasoning. They maximize vessel traffic, increase the allocation of resources, improve protection in port areas, and improve the preservation of the environment.

Improved analytics for prediction, the advent of self-driving and intelligent ports, immediate decision assistance, and relationship to the Internet of Things, including enhanced safety features are some of the newest developments in logic-based Intelligence for ports. The governance of ports is expected to undergo a transformation as a result of these emerging trends.

Although logic-based AI systems have a lot of potential, there are still a number of issues that need to be resolved, including the integrity of data, confidentiality, resource limitations, and legal problems. Future studies should concentrate on creating logic-based AI systems that are scalable, safe, and sensitive to privacy requirements for ports. The long-term viability of the blue economy will also depend on investigating novel logic-based artificial intelligence applications in port efficiency and ethical behavior.

In future, this will further help AI systems to develop its potential into the future, as it provides diverse opportunities while it navigates its challenges to improve the ports in the blue economy in Nigeria. The implication of this is that it creates new and diverse tracks that can facilitate the implementation of AI.

Future research should focus on integrating advanced AI systems with real-time data analytics and predictive tools designed for the blue economy. Prioritizing sustainable development, ethical AI practices, and seamless IoT integration could facilitate autonomous port operations, enhance global maritime connectivity, and promote innovative approaches to tackling climate challenges in port environments

7. LIMITATIONS TO THE STUDY

One significant limitation of this research is the limited availability and quality of data on Nigerian ports, as incomplete or inaccurate information can impede the effective deployment of AI-driven solutions. Moreover, the underdeveloped infrastructure for AI technologies, including high-speed internet, IoT devices, and cloud computing, restricts scalability. The high costs of implementing advanced AI systems pose additional challenges for resource-constrained port authorities. Furthermore, evolving regulatory frameworks for AI in ports may introduce legal and ethical complexities. Lastly, cultural and organizational resistance to technological advancements could further delay the adoption and overall effectiveness of these solutions.

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